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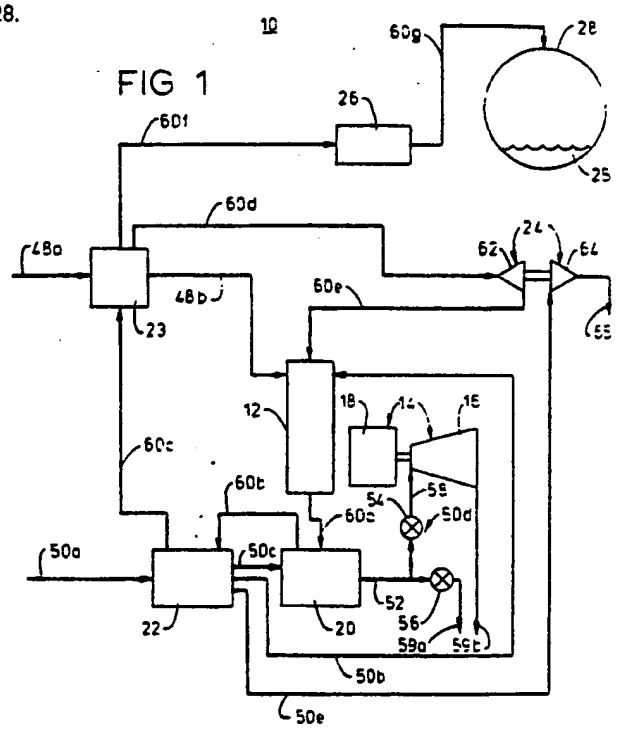
(58) Field of search
UK CL (Edition J) **F1G, F1Q**
INT CL⁴ **F01K, F02C**

(54) Gas turbine electricity generation

(57) The system is for generating electricity in space without release of water. A hydrogen-and-oxygen-burning gas generator 12, having a porous wall (36) (Fig.2) through which water may pass from a space 40, produces a steam exhaust. A turbogenerator 14, 16 is driven by hydrogen conveyed via lines 50a, 50c, 52, 50d, 58 to its turbine 16. The hydrogen is heated in a heat exchanger 20 by the gas generator's steam exhaust 60a which is subsequently condensed to water 60c in the heat exchanger 20 and a further condenser 22. The condensed water passes via a line 60*c* to a heat exchanger 23 to impart heat to liquid oxygen supplied via line 48*a*. The heated oxygen then passes via line 48*b* to the gas generator 12. A portion of the condensed water is passed via lines 60d, 60e and turbopump 24 to the gas generator which is cooled by injecting such water into the combustion region thereof. Any remaining (unused) water is passed via lines, 60f, 60g and a pressure regulator valve 26, to a tank 28.

FIG 1



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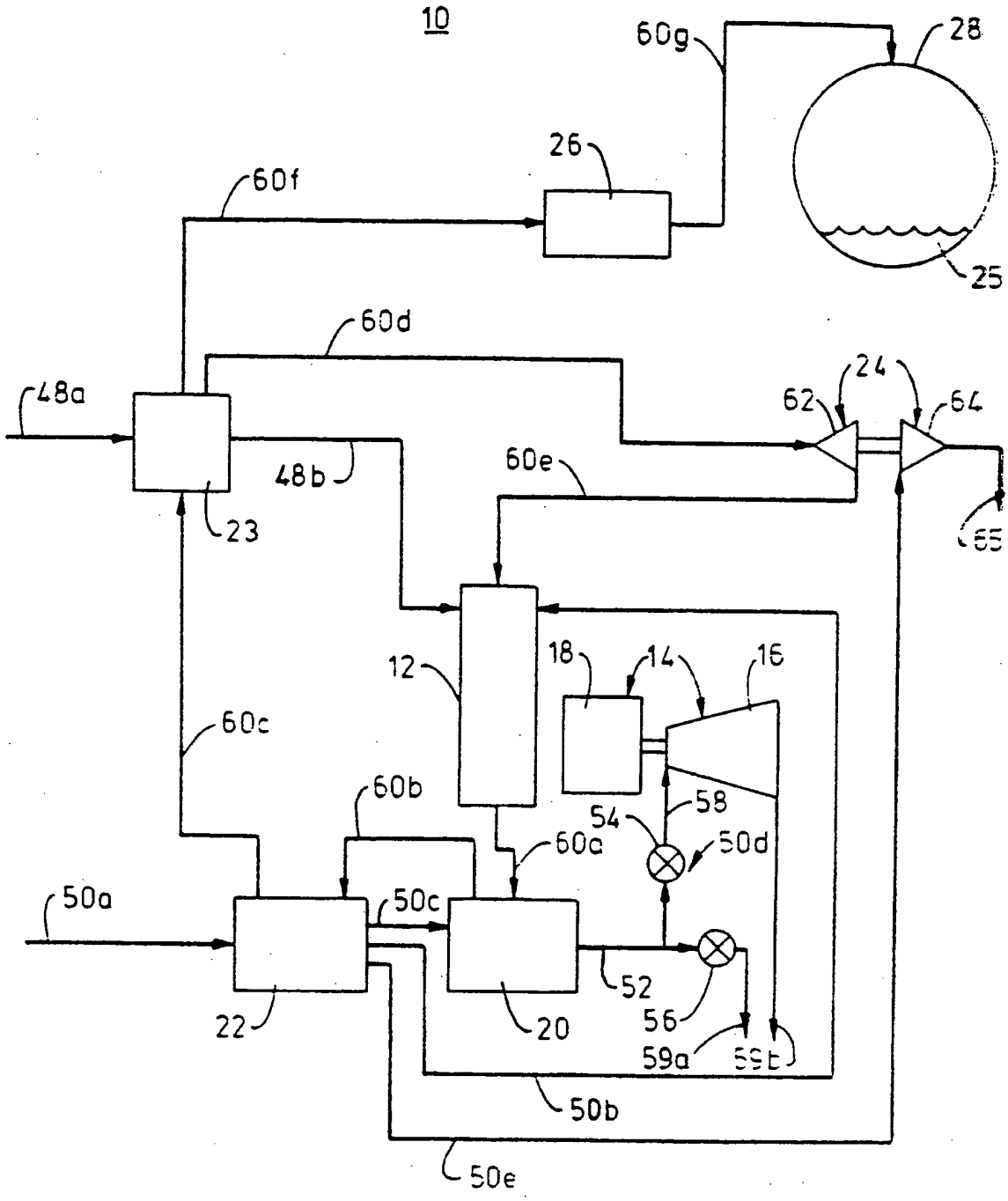
10
60g
28
26
60f
25
60d
48a
24
62
64
48b
60e
23
55
12
18
14
16
60c
60b
58
54
60a
50d
50a
50c
52
22
20
56
59a
59b
50b
50e

FIG. 1

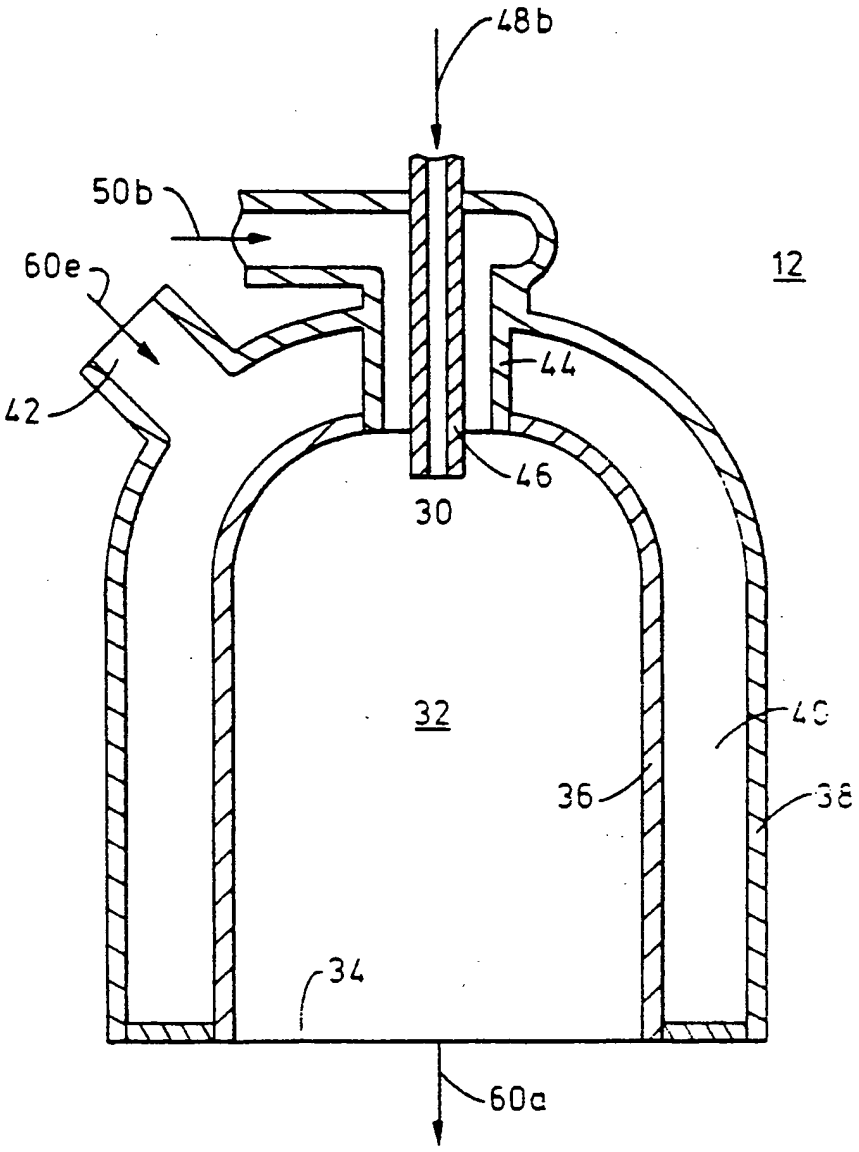

FIG. 2

ELECTRICITY GENERATION

The present invention relates generally to generating electricity. Herein and by way of example, the invention is described in relation to a system and method for generating electricity in a space environment.

Existing systems which can generate electricity for spacecraft (including rockets, space stations, satellites, and the like) have been found unsuitable for certain applications. Batteries and solar energy systems cannot deliver large amounts of electricity (i.e., greater than about one kilowatt) without size and weight penalties. Turbogenerators driven by gas generators cannot produce electricity without releasing water into space.

It is foreseen that future space operations will require an electric generating system capable of delivering large amounts of electricity without water release into space. For example, zero-gravity manufacturing operations onboard an earth-orbiting space station may require large amounts of electricity while the performance of weather monitoring cameras onboard the space station would be degraded if water were released into space as a by-product of the space station's electric generating system.

Illustrative embodiments of the invention seek to:

provide a system and a method for generating large amounts of electricity in a space environment; and/or

generat lectricity in a manner which provides an alternative to using nuclear power; and/or

provide electricity without releasing water into space.

In a first embodiment, the electricity generating system of the invention includes a hydrogen-and-oxygen-burning gas generator, a turbogenerator, apparatus for conveying hydrogen to the gas generator's input region and for conveying hydrogen to the turbogenerator's turbine, and apparatus for conveying oxygen to the gas generator's input region. The system also includes a mechanism for exchanging heat between the gas generator's hot gaseous exhaust (including steam) and the hydrogen being conveyed to the turbogenerator's turbine. The system further includes a mechanism for condensing to water essentially all of the exhaust's steam after the exhaust has exchanged heat with the hydrogen being conveyed to the turbine. The system additionally includes apparatus for conveying at least a portion of the condensed water to the gas generator's combustion region and for storing any remaining condensed water.

In another embodiment, the electricity generating system of the invention includes a hydrogen-and-oxygen-burning gas generator, a turbogenerator, a condenser, a heat exchanger, a

tank, and conveying apparatus. The conveying apparatus includes apparatus for conveying oxyg n to the gas generator's input region and apparatus for conveying hydrogen to the condenser. The conveying apparatus further includes apparatus for conveying hydrogen between the condenser and the gas generator's input region, between the condenser and the heat exchanger, and between the heat exchanger and the turbogenerator's turbine. The conveying apparatus additionally includes apparatus for conveying the exhaust between the gas generator's exhaust outlet and the heat exchanger, between the heat exchanger and the condenser, between the condenser and the gas generator's combustion region, and between the condenser and the tank.

In an alternate embodiment, the electricity generating system of the invention includes a hydrogen-and-oxygen-burning gas generator, a turbogenerator, a condenser, first and second heat exchangers, a tank, and conveying apparatus. The conveying apparatus includes apparatus for conveying oxygen to the first heat exchanger and apparatus for conveying hydrogen to the condenser. The conveying apparatus further includes apparatus for conveying hydrogen between the condenser and the gas generator's input region, between the condenser and the second heat exchanger, and between the second heat exchanger and the turbogenerator's turbine. The conveying apparatus also includes apparatus for conveying oxygen between the first heat exchanger and the gas generator's input region. The conveying apparatus

additionally includ s apparatus for conveying the exhaust between the gas generator's exhaust utlet and the second heat exchanger, b tween the second heat exchanger and the condenser, between the condenser and the first heat exchanger, between the first heat exchanger and the gas generator's combustion region, and between the first heat exchanger and the tank.

In a further embodiment, the electricity generating method of the invention includes conveying hydrogen and oxygen to a gas generator's input region for producing a hot gaseous exhaust including steam from the gas generator's exhaust outlet, and conveying hydrogen to a turbogenerator's turbine. The method also includes exchanging heat between the gas generator's exhaust and the hydrogen which is being conveyed to the turbogenerator's turbine, and condensing to water all of the steam from the exhaust after the exhaust has exchanged heat with the hydrogen which is being conveyed to the turbogenerator's turbine. The method additionally includes conveying at least a portion of the condensed water to the gas generator's combustion region, and storing any of the remaining condensed water.

In a different embodiment, the electricity generating method of the invention is identical to the method embodiment discussed in the previous paragraph except that the step of conveying hydrogen and oxygen to a gas generator's input region for producing a hot gaseous exhaust including steam from the gas generator's exhaust outlet is replaced with a step of conveying a

stoichiometric mixtur f hydrogen and oxygen to a gas generator's input region for producing a steam exhaust from the gas generator's exhaust outlet.

Several benefits and advantages are derived from embodiments of the invention. The turbogenerator feature provides large amounts of electricity. The gas generator feature provides an alternative to nuclear energy. The closed-water cycle operation prevents water from being released into space. The stoichiometric hydrogen-oxygen mixture efficiently utilizes fuel. The gas generator water injection feature cools the gas generator.

For a better understanding of the present invention, reference will now be made, by way of example, to the accompanying drawings, in which:

Figure 1 is a schematic diagram of an illustrative electricity generating system of the invention; and

Figure 2 is a cross-sectional elevational view of the gas generator shown schematically in Figure 1.

The electricity generating system 10 of the invention, as shown in Figure 1, includes a hydrogen-and-oxygen-burning gas generator 12 for producing a hot gaseous exhaust including (and preferably limited to) steam. Briefly stated, the system also includes a turbogenerator 14 having a turbine 16 which turns a

gen rator 18 to produce el ctricity. The turbine 16 is not driven by the exhaust from the gas generator 12 as would be done in a conventional system. Rather, the turbine 16 is driven by heated hydrogen, the hydrogen being heated in a second heat exchanger 20 by a thermal exchange with the gas generator exhaust. Essentially all of the water vapor in that exhaust is condensed to water in a condenser 22 and further cooled in a first heat exchanger 23 by a thermal exchange with oxygen which is being conveyed to the gas generator 12. At least a portion of the water, driven by a turbopump 24, is used to cool the gas generator 12, any unused (remainder of the) water 25 being conveyed through an inlet pressure regulator valve 26 to a storage tank 28.

In further describing the system, reference will be made to means for conveying hydrogen 50a through 50e (including liquid and/or gas), oxygen 48a and 48b (including liquid and/or gas), or exhaust 60a through 60g (including steam, saturated vapor, and/or water). Preferably such means include pipes (or other conduits), manifolds, duct work, valves, and the like for transporting such hydrogen, oxygen, or exhaust, as is known to those skilled in the art. Also, the previously identified heat exchangers and condenser are means for exchanging heat and means for condensing to water and include any type of heat exchanger where the heat exchange between the two substances does not include physical mixing, such as apparatus having two sets of closely-spaced

multiple tubing, apparatus wher in ne substance flows in a housing which is penetrated by multiple tubing of the second substance, and the like.

The hydrogen-and-oxygen-burning gas generator 12, as shown in greater detail in Figure 2, has an input region 30 (to receive hydrogen and oxygen), a combustion region 32 (to ignite the hydrogen and oxygen and to receive the cooling water), and an exhaust outlet 34 found within a generally bell-shaped porous interior wall 36, the inner wall 36 being surrounded by a generally bell-shaped impervious exterior wall 38 so as to create a generally bell-shaped channel 40 therebetween, as is known to be typical of a conventional hydrogen/oxygen rocket engine by those skilled in the art. While a conventional rocket engine is cooled by directing hydrogen into the channel, the hydrogen then passing through the porous inner wall, the gas generator 12 of the invention is cooled by injecting water into the channel 40 through a water inlet 42 in the outer wall 38, the water then passing through the porous inner wall 36 into the combustion region 32. Both walls 36 and 38 of the gas generator 12 are penetrated near the input region 30 by a hydrogen-inlet tube 44 within which is attachingly and coannularly disposed an oxygen-inlet tube 46. The hydrogen and oxygen are ignited in the combustion region 32 by conventional means (not shown), such means not forming a part of this invention, thereby producing a hot gaseous exhaust including steam. When the hydrogen and

oxygen are supplied in a stoichi metric ratio, only steam is produced.

Means 48a are supplied for conveying oxygen to the first heat exchanger 23. Preferably, the oxygen will be in the form f pressurized cold liquid oxygen, such as in a typical rocket engine. The oxygen will leave the first heat exchanger 23 as pressurized oxygen gas where means 48b are supplied for conveying xygen between the first heat exchanger 23 and the input region of the gas generator 12.

Means 50a are supplied for conveying hydrogen to the condenser 22. Preferably, the hydrogen will be in the form of a pressurized cool gas as can be achieved by those skilled in the art. The hydrogen will leave the condenser 22 as a higher-pressurized warm gas where means 50b are supplied for conveying hydrogen between the condenser 22 and the input region of the gas generator 12. For gas generator start-up, additional valves and piping direct the hydrogen and oxygen to a torch ignitor (all not shown), as is commonly known in the rocket engine art.

Means 50c are supplied for conveying hydrogen between the condenser 22 and the second heat exchanger 20. The hydrogen will leave the second heat exchanger 20 as a highly-pressurized hot gas where means 50d are supplied for conveying hydrogen between the second heat exchanger 20 and the turbine 16 to drive the turbogenerator 14 to generate electricity. Preferably, such means 50d include a tube 52 from the second heat exchanger 20

branching to two valves 54 and 56, one valv 54 connected by a tube 58to the turbine 16 and the second valve 56 exhausting to space (at 59a). It is noted that the spent hydrogen exiting the turbine is exhausted to space also (at 59b).

Means 60a, 60b, and 60c are supplied for conveying the gas generator exhaust between the exhaust outlet 34 and the second heat exchanger 20, between the second heat exchanger 20 and the condenser 22, and between the condenser 22 and the first heat exchanger 23. Preferably the exhaust is entirely steam when it enters the second heat exchanger 20, is saturated water vapor when it exits the second heat exchanger 20 and enters the condenser 22, and is hot water when it exits the condenser 22 and enters the first heat exchanger 23.

Means 60d and 60e are supplied for conveying cool water exhaust between the first heat exchanger 23 and the pump portion 62 of the turbopump 24 and between the turbopump 24 and the combustion region of the gas generator 12. To drive the turbopump 24, means 50e are supplied for conveying hydrogen between the condenser 22 and the turbine portion 64 of the turbopump 24. The spent hydrogen exiting the turbine 64 is exhausted to space (at 65). Means 60f and 60g also are supplied for conveying cool water exhaust between the first heat exchanger 23 and the tank's inlet pressure regulator valve 26 and between the inlet pressure regulator valve 26 and the tank 28. The setting on the inlet pressure regulator valve 26 determines what

portion of the exhaust water enters the tank 28 and what portion is injected into the combustion region of the gas generator 12.

The electricity generating method of the invention includes conveying hydrogen and oxygen to the input region 30 of the gas generator 12 for producing a hot gaseous exhaust including steam from the exhaust outlet 34 of the gas generator 12. Additional steps in the method include conveying hydrogen to a turbine 16 of a turbogenerator 14, exchanging heat between the exhaust and the hydrogen being conveyed to the turbine 16. Other steps include condensing to water essentially all of the steam from the exhaust after the exhaust has exchanged heat with the hydrogen being conveyed to the turbine 16, conveying at least a portion of the condensed water to the combustion region 32 of the gas generator 12, and storing any remainder of the condensed water. Preferably a generally stoichiometric mixture of hydrogen and oxygen is conveyed to the gas generator input region 30 for producing a generally steam exhaust from the gas generator exhaust outlet 34.

It is noted that if the system is operated such that any gas in the exhaust remains after the first heat exchanger 23, the entire exhaust output from that heat exchanger 23, in an optional design, could be conveyed to the inlet pressure regulator valve 26 and the tank 28. The tank 28 would contain a gas separator (a hydrogen separator in the case where the system is operated to favor hydrogen production in a predominantly steam exhaust) and a vent to exhaust the gas to space (both not shown). Means (not

shown) would then be supplied t convey water from the tank 28 to the pump portion 62 of the turbopump 24. The operation f the system of the invention can be understood by those skilled in the art from the foregoing description, and the control of the system (supply conditions for the hydrogen and oxygen, setting of the inlet pressure regulator valve 26, setting of the turbogenerator turbine hydrogen input 54 and bypass 56 valves, etc.) is not described as it is within the skill and knowledge of those skilled in the art of control systems suitable for the electricity generator.

The foregoing description of several preferred embodiments of the invention has been presented for purposes of illustration. It is not intended to be exhaustive or to limit the invention in the precise form disclosed, and obviously many modifications and variations are possible in light of the above teaching.

CLAIMS:

1. A system for generating electricity comprising:

(a) a hydrogen-and-oxygen-burning gas generator for producing a hot gaseous exhaust including steam, said gas g nerator having an input region, a combustion region, and an exhaust outlet;

(b) a turbogenerator having a turbine;

(c) means for conveying hydrogen to said input region of said gas generator and for conveying hydrogen to said turbine;

(d) means for conveying oxygen to said input region of said gas generator;

(e) means for exchanging heat between said exhaust and said hydrogen being conveyed to said turbine;

(f) means for condensing to water essentially all of said steam from said exhaust after said exhaust has exchanged heat with said hydrogen being conveyed to said turbine; and

(g) means for conveying at least a portion of said condensed water to said combustion region of said gas generator and for storing any remainder of said condensed water.

2. A system for generating electricity comprising:

(a) a hydrogen-and-oxygen-burning gas generator for producing a hot gaseous exhaust including steam, said gas generator having an input region, a combustion region, and an

exhaust outlet;

(b) m ans for conveying oxygen to said input region of said gas generator;

(c) a condenser;

(d) means for conveying hydrogen to said condenser

(e) a heat exchanger;

(f) a turbogenerator having a turbine;

(h) means for conveying hydrogen between said condenser and said input region of said gas generator, between said condenser and said heat exchanger, and between said heat exchanger and said turbine;

(i) a tank; and

(j) means for conveying said exhaust between said exhaust outlet and said heat exchanger, between said heat exchanger and said condenser, between said condenser and said combustion region of said gas generator, and between said condenser and said tank.

3. A system for generating electricity comprising:

(a) a hydrogen-and-oxygen-burning gas generator for producing a hot gaseous exhaust including steam, said gas generator having an input region, a combustion region, and an exhaust outlet;

(b) a first heat exchanger

(c) means for conveying oxygen to said first heat exchanger;

(d) a cond nser;

(e) means for conveying hydrogen to said condenser

(f) a second heat exchanger;

(g) a turbogenerator having a turbine;

(h) means for conveying hydrogen between said condenser and said input region of said gas generator; between said condenser and said second heat exchanger, and between said second heat exchanger and said turbine;

(i) means for conveying oxygen between said first heat exchanger and said input region of said gas generator;

(j) a tank; and

(k) means for conveying said exhaust between said exhaust outlet and said second heat exchanger, between said second heat exchanger and said condenser, between said condenser and said first heat exchanger, between said first heat exchanger and said combustion region of said gas generator, and between said first heat exchanger and said tank.

4. The system of claim 3 wherein said exhaust conveying means between said first heat exchanger and said combustion region of said gas generator includes a turbopump, said system also including means for conveying hydrogen between said condenser and said turbopump.

5. The system of claim 4, wherein said tank includes an inlet

pressure regulator valve and said exhaust conveying means between said first heat exchanger and said tank includes means for conveying said exhaust between said first heat exchanger and said inlet pressure regulator valve.

6. A method for generating electricity comprising:

(a) conveying hydrogen and oxygen to an input region of a gas generator for producing a hot gaseous exhaust including steam from an exhaust outlet of said gas generator;

(b) conveying hydrogen to a turbine of a turbogenerator;

(c) exchanging heat between said exhaust and said hydrogen being conveyed to said turbine;

(d) condensing to water essentially all of said steam from said exhaust after said exhaust has exchanged heat with said hydrogen being conveyed to said turbine;

(e) conveying at least a portion of said condensed water to a combustion region of said gas generator; and

(f) storing any remainder of said condensed water.

7. A method for generating electricity comprising:

(a) conveying a generally stoichiometric mixture of hydrogen and oxygen to an input region of a gas generator for producing a generally steam exhaust from an exhaust outlet of said gas generator;

(b) conveying hydrogen to a turbine of a turbogenerator;

(c) xchanging h at b tw en said xhaust and said hydrogen being conveyed to said turbine;

(d) condensing to water essentially all of said steam exhaust after said steam exhaust has exchanged heat with said hydrogen being conveyed to said turbine;

(e) conveying at least a portion of said condensed water to a combustion region of said gas generator; and

(f) storing any remainder of said condensed water.

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